THE DYNAMICS OF COBBLES IN AND NEAR THE SURF ZONE
and
MINE MOVEMENT IN AND NEAR THE SURF ZONE

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LONG-TERM GOAL

The long-term goal of this program is to develop, by laboratory experimentation, theoretical analyses and comparisons with field observations, a basic understanding and, eventually, a predictive capability of the behavior of large bottom particles (cobbles) in the shoaling, wave-breaking and swash zones. The American Geophysical Union defines cobbles as particles in the diameter range 6.4 to 25.6 cm. Disk-shaped anti-tank mines are of similar size.

SCIENTIFIC OBJECTIVES

The scientific objectives of this research are directed toward better understanding (a) the motion of cobbles on sloping beaches which have a range of roughness characteristics, and (b) the motion and/or burial/scouring of cobbles on sloping beaches that are permeable and have sand bed forms that are non-stationary as forced by the local current and wave motions.

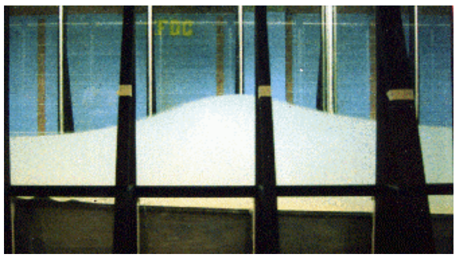
The objectives for the impermeable floor case are to (i) mimic the water motion in a shoaling region of a surf zone in a large wave tank and to obtain information on the background water velocity field, (iii) extend the models of cobble transport, previously developed for idealized basic time-dependent flows, to include spatially and temporally-dependent flow in a surf zone, and (iii) obtain experimental data on the transport of cobbles in the model surf zone and test the model against the experimental data.

The objectives of the permeable sandy floor case are to (i) study the evolution of an initially flat sandy bottom in periodic wave-induced flow and clarify the long-time dynamics of the bottom topography, (ii) enhance the database on the process of burial/scouring of cobbles on a sandy bed and (iii) determine the eventual long-time fate of model cobbles.

APPROACH

Carefully designed laboratory experiments are key to the achieving of stated scientific goals. The experiments were conducted using wave tanks located at Arizona State University. One of the tanks (32 x 1.8 x 0.9 m) includes a computer-controlled wave maker and a sloping beach; the facility can accommodate solid as well as sandy beaches. Acoustic Doppler velocimeter (ADV), wave gauges, traversing platforms, data acquisition systems and other standard methods are used to determine the background flow characteristics. Cobble motions are monitored by employing video cameras and the resulting data are analyzed using standard software. Based on the results of experiments, theoretical models will be developed and tested.

(a)



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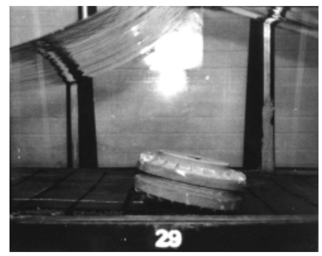


(c)

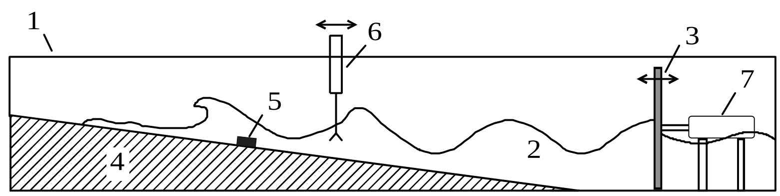
Figure 1. (a) Side view of the central part of the large wave tank, 32 x 0.9 x 1.8 m. Numbers show the sections as counted from the wave maker, which is at the right end of the tank. The distance between vertical bars is 61 cm. (b) Typical non-linear wave propagating from right to left in the central part of the tank. (c) Cobble 2 (replica of anti-tank mine) during its forward motion (from right to left) in section 29.

WORK COMPLETED

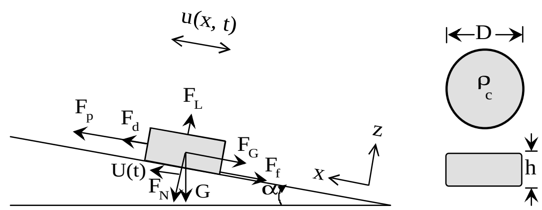
Periodic and spatially dependent water motion in a shoaling surf zone was mimicked in the large wave tank with a slope (Fig. 1a), which was constructed under the present grant. Data on the water velocity induced by periodic progressive waves propagating along the slope (Fig. 1b) were taken at different depths and distances along the slope and were analyzed. Large disk-shaped bottom particles (Fig. 1c) of different sizes and densities were placed on a slope with artificial roughness and their motion in a model surf flow was studied. The models for cobble motion, which were developed previously for idealized basic flows configurations (Luccio et al., 1998; Voropayev et al., 1998), were refined and extended to the flow conditions being considered. The results of observations were compared with model estimates.

RESULTS

Our research for the FY 99 was concentrated mostly on cobble motions along the slope under conditions similar to those occurring in a shoaling surf zone with an impermeable bed. The principal outcomes to date are as follows.



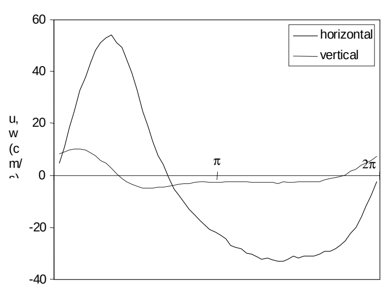
(a)

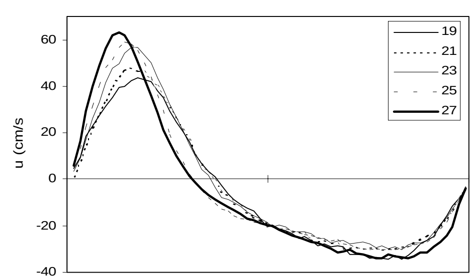


(b)

Figure 2. (a) Schematic diagram of the experimental system: 1 - tank, 2 - water, 3 – vertical wave-maker (frequency ω, horizontal displacement ε), 4 – sloping bottom, 5 – cobble, 6 – acoustic Doppler velocimeter (ADV) attached to carriage, 7 – hydraulic system to move the wave maker. (b) Definition sketch with coordinate system and periodic forces that act on a cobble placed on a sloping beach in a surf zone.

For the flow configuration used, there is no satisfactory theory that may be used to estimate accurately the water particle velocities u(x,t) associated with the motion of non-linear waves propagating along the slope. As these data are needed to calculate accurately the cobble motion, direct measurements were made using a three-component acoustic Doppler velocimeter (ADV). The initial data on velocity were obtained as time series at points in different sections of the tank and at different distances from the bottom, and then were phase averaged. Typical examples are shown in Fig. 3. These data were used as inputs for model calculations.

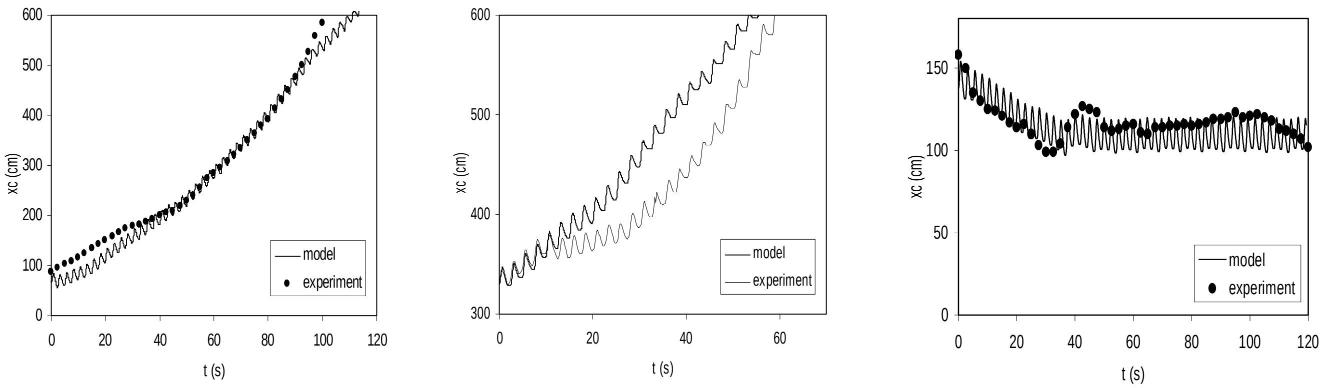




(a) (b)

Figure 3. (a) Horizontal (u) and vertical (w) components of the water velocity under a periodic wave along the slope. Section #25, depth is 10 cm above the bottom. The data are averaged over 40 wave periods. (b) Horizontal water velocities (u) as function of position in the wave tank. The data were taken in sections #19, 21, 23 25 and 27 at depth 10 cm from the bottom. Standard phase averaging was applied. Section numbers are shown in the legend.

In the experiments, cobbles of different sizes were placed along the floor and their motion with time was studied and compared with the theoretical predictions. Onshore and offshore mean motions of cobbles, as well as steady oscillations with zero mean displacement, were observed for different conditions; some typical examples are shown in Figs. 4. For the range of parameters used in the experiments, satisfactory agreement between the measured and calculated values of cobble displacements as a function of time was obtained.



(a) (b) (c)

Figure 4. Calculated and measured cobble positions x_C as a function of time t: (a) for cobble B, which was placed above the critical position for onshore motion; (b) for cobble 1, which was placed above the critical position; (c) for cobble 1, which was place below the critical position and moved offshore.

The model takes into account all governing parameters (size and density of cobbles, bottom slope, dynamic and static friction at the bottom, background flow characteristics). Standard parameterizations were used for a pressure accelerating term, drag, lift and other nonlinear forces. Comparison of measured and calculated values for the cobble displacement shows that the model is practically insensitive to the vertical accelerating pressure term, and is sensitive to the dynamic friction. The use of static friction does not improve predictions and makes predictions only worse. One of the most important variables in the model, which is known with the least accuracy, is the virtual mass coefficient for a disc moving with variable velocity along a solid boundary. Fixed values were used for this coefficient, as were for drag and lift coefficients. Note that the spatial variation of the periodic background velocity along the slope must be taken into account in calculations. If this is not done, the cobbles move with some constant net velocity along the slope in contrast with observations. The main results are reported in Voropayev et al. (1999b).

Recently, the far more complex (and more realistic) case of sand covered floors was studied under this grant for a simplified background flow induced by periodic standing waves (Voropayev et al. 1999 a). Since the long-time instability of the bottom topography observed in these studies will be of great importance for periodic burring of cobbles in a surf zone, a series of related experiments was conducted in a model surf zone. The main efforts are concentrated on cobble behavior in the presence of the sandy movable coastal floor. In these preliminary experiments, a layer of sand was placed on the slope in the large wave tank and the long-time evolution of the bottom topography was studied. At present the results are being analyzed.

IMPACT/APPLICATIONS

The transport of "heavy particles", such as cobbles, on a sloping bottom submerged in a periodic spatially dependent flow, typical of a surf zone, is not well understood from a fundamental point of view. The present project is an integrated laboratory, theoretical and field program that seeks to better understand this complex physical problem.

TRANSITIONS

Discussions between Dr. Todd Holland from the Naval Research Laboratory and project personnel at Arizona State University are being held to develop a knowledge base that can be transitioned to the Navy.

RELATED PROJECTS

This project is linked to a field observational and modeling program that was carried out by personnel of the Naval Research Laboratory (NRL) at the Stennis Space Center under the direction of Dr. Todd Holland. Close collaboration between the laboratory/theoretical studies at Arizona State University and the mine-motion observation/modeling studies of NRL is being effected.

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